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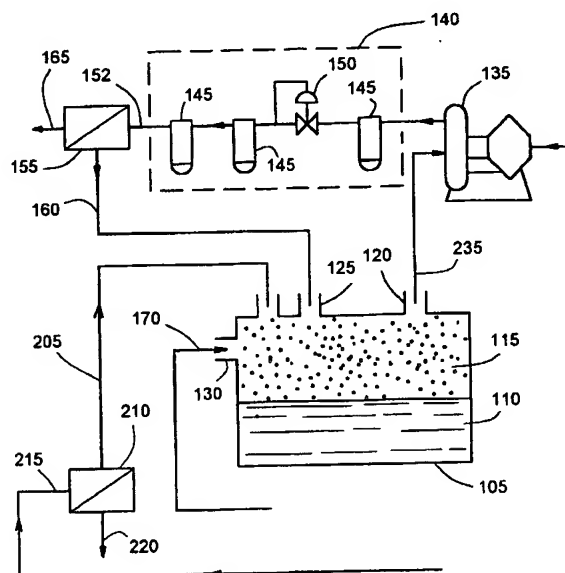
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(54) Title: AIRCRAFT FUEL TANK INERTING



(57) Abstract: An inerting system for inerting a flammable gas comprising a flammable vapor and oxygen in a vented, controlled atmosphere container (105) is described. A method of inerting involves compressing the flammable gas (115), removing oxygen from the compressed gas utilizing a separator (135) and feeding oxygen-depleted gas to the container. Also addressed is a method of reducing the potential for hazard from combustion of an aircraft fuel tank. The method calls for removing a fraction of the oxygen from ambient air at the aircraft fuel dispensing site and using the resulting nitrogen enriched gas to reduce the oxygen concentration within the aircraft fuel tank of an on-ground aircraft. Ullage washing and/or fuel scrubbing are used to reduce the oxygen concentration. A system located at or near an airport for providing reduced oxygen content aircraft fuel and for ullage washing of aircraft fuel tanks is also disclosed.

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AIRCRAFT FUEL TANK INERTING

This invention relates in part to a vented compartment inerting device and method for quickly and selectively rendering nonexplosive a vented compartment initially containing an explosive concentration of a flammable vapor. It is also directed to protecting aircraft fuel tanks from explosion hazards. In this aspect it more specifically relates to on-ground inert gas facilities to produce inert gas and to purge oxygen from aircraft fuel and fuel tanks. In another aspect it pertains to a system primarily located at airports and a process utilizing inert gas to reduce the oxygen content of the head space and the aircraft fuel in the tanks

Recently a number of aircraft explosions have occurred which resulted in loss of life, injury to persons and extensive destruction of property. Cause for many of these explosions has been attributed to the detonation and catastrophic combustion of fuel in the fuel tanks of the aircraft. The commercial aircraft industry, authorities that regulate the industry and users of commercial aircraft are concerned about safety from fuel tank explosions. There is a great need for technological advances to reducing the risk of this hazard.

The U.S Federal Aviation Administration has studied various potential solutions for reducing the risk of fuel tank explosions, such as reducing the heat input to tanks by ventilation, relocation of the tanks to safer positions on the aircraft, and altering fuel properties for example by raising the flash point. However, relocation of the fuel tanks is only feasible on new airplanes; full-time ventilation of the fuel tanks is estimated to be very costly (over 3.5 billion dollars over ten years), and alteration of the fuel flash point is estimated to be even more costly (over 75 billion dollars worldwide over ten years).

In operation, aircraft fuel tanks contain a liquid inventory of aircraft fuel and a vapor composition in the space within the tank not occupied by the liquid fuel. This space is often referred to as the "ullage" of the tank. Oxygen mixed with fuel vapor is usually present in the ullage. One likely cause of fuel tank explosions is the simultaneous combination of an explosively combustible mixture of oxygen and fuel vapor in the ullage and a source of ignition. Such ignition sources are due to accidental fire, sparking due to faulty or degraded electrical system components, static electricity discharge, or energy suddenly released on impact by collision with an object, for example. If the oxygen-fuel vapor explodes, it is likely to destroy the integrity of the tank and thereby release more fuel to exacerbate the disaster.

One way to negate the possibility of an explosively combustible oxygen-fuel vapor mixture forming in an aircraft fuel tank is to prevent the concentration of oxygen in the ullage from exceeding the minimum limits for flammability. Oxygen can enter the ullage

in gaseous form when fuel is consumed by the aircraft engines. That is, as the fuel is consumed, the level of liquid fuel in the tank is lowered, which draws in ambient air containing about 21 vol. % oxygen from outside the tank to fill the void created by the vacated fuel.

5 Oxygen can also enter the tank with the fuel. For example, oxygen dissolves in the fuel when the fuel is stored in vented storage tanks at an airport prior to filling the aircraft fuel tank. That is, due to vapor-liquid equilibrium, some of the oxygen present in the atmosphere above the fuel diffuses and dissolves into the liquid phase. In flight, the local ambient pressure drops due to the change of aircraft altitude. The vapor liquid
10 equilibrium shifts to favor liberation of substantial amounts of the dissolved oxygen into the ullage vapor as the pressure goes down.

 Oxygen concentration of the fuel tank ullage can be reduced by initially purging it from the tank and replenishing the volume voided during fuel consumption with an inert gas. Nitrogen is a preferred inert gas because it is relatively plentiful and inexpensive.
15 The procedure of displacing the vapor in the ullage with one of different and safer, (*i.e.*, less explosive) concentration or composition is sometimes referred to herein as "ullage washing". Also, the liquid fuel can be purged to very low concentrations of oxygen prior to filling the tank. The latter process typically involves contacting the liquid fuel with large quantities of inert gas. The dissolved oxygen redistributes between the liquid and
20 the low oxygen content scrubbing gas which is swept away leaving less oxygen in the fuel. The procedure of removing dissolved oxygen from liquid fuel is sometimes referred to herein as "fuel scrubbing".

 Ullage washing and fuel scrubbing each depend on the availability of an adequate supply of a suitable inert gas. Conventional cryogenic methods of producing sufficient
25 quantities of oxygen-free or nearly free inert gas operate at extreme temperatures and pressures. They usually utilize large, heavy, complex and often noisy machinery that draws large amounts of power to operate. Cryogenic inert gas production facilities are also usually expensive. These factors normally promote location of such facilities remotely from commercial aircraft fuel tank dispensing sites and airport passenger
30 terminal buildings. Cryogenic inert gas production typically results in a highly pressurized inert material in liquid form, for example, liquid nitrogen, which is stored at well below ambient temperature. Body contact with liquid nitrogen can cause serious personal injury.

 Various methods exist for separating mixtures of gases for the production or
35 purification of nitrogen and oxygen. Current methods include both selectively permeable membranes and pressure swing absorption. Selectively permeable membranes work by passing a mixture of gases over a membrane that has a relatively high permeability to one

of the gases, and a relatively low permeability to the other gas. For example, a membrane that is more permeable to oxygen than to nitrogen may be used to separate oxygen from an air stream by flowing air through such a membrane. The oxygen will pass through and may be recaptured on the other side of the membrane, while the nitrogen will not pass through. Pressure swing absorption systems use selectively absorbent beds into which a mixture of gases is introduced under high pressure. U.S. Patent 4,194,891 describes such a bed for the separation of oxygen from air. An alternating exposure of high and low pressures causes the beds to release oxygen at a relatively faster rate than the beds release nitrogen.

It is known to try to use inert gases to displace oxygen over supplies of flammable liquids where it is desired to avoid the formation of explosive gases. U.S. Patent 5,858,064 discusses producing nitrogen produced by a gas separation system and a method for introducing nitrogen into and through a crankcase for inerting the interior of the crankcase. But merely blowing an inert gas into a vented fuel compartment is not a desirable or effective solution. A problem that exists is that introduction of a volume of nitrogen into a vented fuel tank will necessarily cause venting of an equivalent volume of ullage from the compartment. This exhaust includes a potentially flammable mixture of oxygen and fuel vapors. Even if this mixture is captured and safely handled, the removal of the displaced fuel vapors can add up to a large loss of valuable fuel and have a significant impact on the environment by the needless dumping of the hydrocarbon fuel into the atmosphere.

International Patent Publication WO 99/34106 discloses a method for providing inert loading jet fuel for use in cold fuel, hot fuel or conventional temperature fuel applications for aircraft. An inerting agent is suspended within the fuel flow and outgases into the ullage of the fuel storage of the aircraft in less than ten minutes, and then vents as a gas through fuel storage vents of the aircraft over a period of three hours or more. In Fig. 1 of this publication it is seen that the spent inerting material exhausts to ambient atmosphere. Such exhaust is mixed with volatile organic components of fuel vapor which pollutes the ambient atmosphere and thereby creates risk of damage to health of personnel in the area and to the environment. Hence, it is desirable to provide an aircraft fuel tank inerting system that produces significantly less air pollution than conventional practices.

A need therefore exists for a relatively inexpensive method and apparatus for inerting the ullage in a fuel tank without losing fuel or fuel vapors while minimizing the risk of fire or explosion and without making the cost prohibitive in terms of equipment or the need for added weight on an aircraft. There also is a need for methods and systems for aircraft fuel tank ullage washing and aircraft fuel scrubbing at or near airports to reduce

the risk of hazard from fuel tank explosions. There is also a need for an airport-based aircraft fuel and fuel tank inerting system adapted to capture volatile organic components of vapor in equilibrium with the aircraft fuel so as to reduce the hazard of explosion of aircraft fuel tanks while protecting the environment from excessive organic emissions.

5 Fuel tank inerting can be effected either on each airplane or on the ground prior to and after flights. In-plane inerting would have the advantage of being tailorable for each plane. Ground inerting would have the advantage of being less expensive to maintain, as it could be a single system at selected airports, rather than a system in each plane. Ground inerting also provides the advantage of not requiring the additional weight on the
10 plane attributable to the presence of an inerting apparatus on the plane. Both methods may be employed together as an extra level of safety that will minimize the amount of time that an explosive mixture exists in the fuel tanks.

In a first aspect the present invention fulfills the above need and fills the voids in the prior art by providing a system for inerting a vented compartment that comprises a
15 system for separating the oxygen from the mixture of air and flammable vapor present in tank ullage and returning the oxygen depleted hydrocarbon/nitrogen mixture to the compartment. Some embodiments of the invention can be understood with reference to Figs. 1-3.

Figure 1 is a schematic diagram of a first embodiment of a vented compartment
20 inerting system of the present invention. Table 1 shows the relative flow rates, pressures, and temperatures of flows of gas in this embodiment. The vented fuel tank 105 contains a supply of a liquid hydrocarbon (HC) 110, and the vapor in the ullage 115 above the HC 110 is a gaseous mixture of HC, oxygen (O_2), and nitrogen (N_2). The tank 105 has an outlet 120, an intake 125, and a vent 130. In a first embodiment of the present invention,
25 tank ullage vapor 115 is taken from the tank 105 and fed through a conduit to a compressor 135. The compressor 135 can be of any type, however, a turbine driven compressor would be preferred where energy from a turbine is available, for instance, a jet engine on an airplane. The compressor 135 compresses the ullage vapor, and the compressed HC, O_2 and N_2 is then routed to an air conditioning stage 140 where it is
30 passed through one or more coalescing filters 145 and a pressure regulator 150 to lower the pressure to prepare the compressed ullage for a separator, and optionally a heat exchanger.

The separator 155 can be any type known in the art that is suitable for handling a mixture of hydrocarbons and air, including selectively permeable membrane separators,
35 pressure swing absorption separators, or any other separator that can selectively remove oxygen from a mixture of air and hydrocarbons, leaving oxygen enriched air (OEA) and hydrocarbons in nitrogen enriched air (NEA).

The conditioned stream 152 exits the air conditioning stage 140 and enters the separator 155, where it is divided into a NEA stream 160 that is mostly HC and N₂ with traces of O₂, and a OEA permeate stream 165 of O₂ with traces of HC and N₂. The OEA permeate can be exhausted; the trace levels of HC in the permeate flow can be recaptured or exhausted. The NEA stream 160 exits the separator 155 and is routed back to the tank 105.

Table 1

Relative Flow Rates, Pressures, and Temperatures of Gas Flows in a First Embodiment of The Present Invention			
Direction of flow	Flow Rate	Pressure	Temperature
From tank to compressor	F ₁	P _{amb}	T _{amb}
From compressor to regulator	F ₁	P _{comp}	-----
From regulator to separator	F ₁	P ₁	T ₁
NEA from separator to tank	F ₂	P ₂	-----
OEA from separator	F ₃	P _{amb}	-----
Tank vent flow	F ₄	P _{amb}	T _{amb}
Turbine drive flow	F ₅	P ₃	T ₂

Because the vented tank 105 has a fixed volume, and because a volume of gas has been removed from the tank 105 equivalent to the flow F₃ of OEA stream 165 from the separator 155, make up gas must be supplied to the tank 105 in order to maintain ambient pressure. This make up gas can be in the form of make up air 170 admitted to the tank 105 through the tank vent 130.

The percentage of oxygen in the ullage vapor 115 desirably should be less than 15%, preferably less than 12%, and more preferably less than 9% to significantly reduce the risk of fire or explosion. Because the O₂ in the make up air 170 is approximately 20.9% if ambient air is used, significantly decreased time to inert the tank 105 can be achieved by lowering the level of O₂ in the make up gas prior to introducing the make up gas into the tank 105. This is the basis of a second embodiment of the present invention. Figure 2 shows a schematic of this second embodiment, which includes a modification that precludes the need for a second compressor. In this second embodiment, a significant percentage of make up gas that is routed to the tank 105 to replace the separated OEA stream 165 from the first separator comes from an NEA stream 205 taken from a second separator 210.

As in the first embodiment, ullage vapor 115 from the tank 105 is routed to a turbine driven compressor 135, which compresses the ullage vapor and passes it to conditioning

equipment 140, including filters 145 and a pressure regulator 150, and optionally a heat exchanger (not shown). The conditioned stream 152 from the conditioning equipment 140 is fed to a first separator 155, from which the OEA stream 165 is exhausted and the NEA stream 160 is fed to the tank 105.

5 However, in this embodiment, a make up NEA stream 205 for the tank 105 that replaces the volume of OEA 165 from the first separator 155 comes from a second separator 210. Compressed air 215 is fed to this second separator 210, which separates the air into a second OEA stream 220 and a make up NEA stream 205. The OEA stream 220 is exhausted, while the make up NEA stream 205 is fed to the tank 105 in sufficient
10 flow rate to replace the volume of gas lost to the OEA stream 165 from the first separator 155. In this way, the net volumetric flow from the tank 105 is zero, which precludes the need for any ambient make up air 170. Table 2 shows the relative flow rates, pressures, and temperatures of gas flows in this second embodiment.

15 Advantageously, because the O₂ level in the make up NEA gas 205 is near zero, the inerting of the tank 105 can be accomplished in a significantly reduced time relative to the time needed by an apparatus that uses only ambient make up air 170. It should be noted that it is not necessary to employ a second separator for the production of nitrogen enriched/oxygen depleted make up air. It would work as well to simply add a sufficient
20 supply of make up air to the ullage stream 235 from the tank 105 prior to its entering the compressor 135. In this way, the NEA flow 160 from the single separator 165 will be sufficient to maintain a zero net flow into the tank 105 without the need for adding ambient make up air 170 through the vent 130.

Table 2

Relative Flow Rates, Pressures, and Temperatures of Gas Flows In a Second Embodiment of The Present Invention				
5	Direction of flow	Flow Rate	Pressure	Temperature
	From tank to compressor	F_1	P_{amb}	T_{amb}
	From compressor to regulator	F_1	P_{comp}	
	From regulator to separator	F_1	P_1	T_1
	NEA from first separator to	F_2	P_2	
10	tank			
	OEA from first separator	F_3	P_{amb}	
	Intake for second separator	F_6	P_3	T_3
	NEA from second separator	F_3	P_4	
	to tank			
15	OEA from second separator	F_7	P_{amb}	
	Tank vent flow	F_4	P_{amb}	T_{amb}
	Turbine drive flow	F_5	P_3	T_2

20 As an energy saving modification of this second embodiment which may be understood with reference to Fig. 3, the compressed air flow 215 to the second separator 210 is taken as a bleed 230 from the turbine drive flow for the compressor 135. The excess air from the turbine 135 is already under pressure as it leaves the turbine 135, and does not need to be compressed prior to entry into the second separator 210. This
25 modification is enabled by the presence of a turbine 135, such as would be found on a jet powered airplane.

In a second aspect the present invention concerns reducing the explosion hazard of an aircraft fuel tank by providing a non-explosively combustible vapor above the liquid fuel in the tank as will now be explained. By non-explosively combustible vapor is
30 meant a gas that does not commence combustion when brought into contact with an ignition source. Preferably, the non-explosively combustible vapor is a gas containing less than 12 vol. % oxygen, more preferably less than 9 vol. %, and most preferably, less than 5 vol. %.

In an embodiment, this invention is directed to removing oxygen from the liquid fuel prior to charging the fuel to the tank, *i.e.*, "fuel scrubbing". The objective of fuel
35 scrubbing is to provide a liquid fuel which is substantially free of dissolved oxygen. The term "substantially free of dissolved oxygen" means that the oxygen present in scrubbed fuel is low enough that the amount of oxygen to be liberated if it were to vaporize into the ullage under normal fuel tank operating conditions would be insufficient to produce

an explosively combustible vapor. Hence, there can be a small amount of dissolved oxygen in the scrubbed fuel. Preferably, the concentration of dissolved oxygen in the scrubbed fuel should be such that partial pressure of oxygen is at most about 20.7 kPa absolute (3 psia).

5 Preferably fuel scrubbing is accomplished by contacting the liquid fuel having an initial concentration of dissolved oxygen with an inert gas which itself has a low concentration of oxygen. The inert gas and fuel are brought into intimate contact so that vapor liquid equilibrium is nearly established. This causes the oxygen in the fuel to fractionate between the liquid and vapor phases so that the oxygen transfers to the vapor,
10 depleting the oxygen in the fuel. The vapor bearing just liberated oxygen is then removed. The dissolved oxygen content of the fuel and the oxygen concentration in the ullage are thus reduced. This type of scrubbing can be performed by sparging in which inert gas is bubbled through a volume of the liquid to be stripped of oxygen. The inert gas can be blown into the liquid through a fritted fitting or similar gas dispersing nozzle
15 designed to generate very small gas bubbles. Small gas bubbles are preferred because the surface to gas volume ratio increases inversely with bubble size and large interfacial area promotes transfer of oxygen to the stripping gas. Preferably the stripping gas is nitrogen.

Preference is given to scrubbing the fuel in bulk and dispensing the scrubbed fuel
20 from strategically located depots. Usually, aircraft tanks take on large quantities of fuel which is delivered to the aircraft from bulk storage facilities via pipeline distribution systems or tank trucks. Fuel is normally loaded into the mobile fuel tank trucks from massive stationary tanks. For sake of safety, these stationary tanks are located in a tank farm at some distance from airport operations. Ideally the fuel should be scrubbed in the
25 stationary tanks. Oxygen dissolves into the fuel relatively slowly. Scrubbed fuel will thus tend to remain at acceptably low dissolved oxygen content for some time despite contact with oxygen bearing air. Nevertheless, if scrubbing is performed on the fuel in the stationary tanks, reasonable care should be taken to prevent oxygen from re-entering the fuel when it is transferred from stationary tank to cargo tank and again from cargo
30 tank to aircraft fuel tank.

The stripping gas is preferably selected to have little intrinsic value and therefore the spent stripping gas is considered waste product. The stripping gas containing oxygen removed from the fuel is also expected to contain fuel vapor. Relative to the stripping gas, the amount of fuel vapor should represent a very small fraction of the total.
35 However, due to the large volume of stripping gas, the absolute amount of fuel in the vapor normally is not insubstantial. Hence the spent stripping gas should not be

discarded simply by discharge to the ambient atmosphere. Such venting of volatile organic compositions is likely to be prohibited by pollution control regulations.

In another aspect the present invention provides for cleaning a significant amount of the fuel from the spent stripping gas before discarding it, for example, by emitting the spent gas to ambient atmosphere. Preferably a major fraction of the volatile organic components in the waste stripping gas is removed. After being separated from the spent stripping gas, the volatile organic components can be destroyed, as by incinerating in a furnace, and optionally, the energy of incineration can be recovered for its heat value. The separated volatile organic components can also be collected and recycled for fuel value. Representative methods of cleaning the fuel vapor from the spent stripping gas include absorption, adsorption and condensation unit operations.

In another embodiment, this invention pertains to purging the fuel tank ullage of oxygen, *i.e.*, "ullage washing". This generally involves flushing the ullage with a flow of inert gas having a lower concentration of oxygen than initially present in the ullage. The incoming inert gas mixes with the vapor present in the ullage prior and during washing and pushes an equal volume of mixed gas out of the tank. The gas pushed out contains only a fraction of the oxygen in the ullage prior to washing. Consequently, the ullage will deplete of oxygen as washing continues. Ullage washing should proceed until a satisfactorily inert oxygen-fuel vapor mixture is produced in the tank.

Ullage washing can be performed on tanks at any fuel inventory level. The greater the amount of liquid fuel in the tank, the smaller the ullage, and therefore, the less inert gas ullage washing that should be needed to reduce the oxygen concentration to any given amount. The ullage washing flow of inert gas should be introduced into the fuel tank above the liquid fuel to avoid bubbling through the fuel and entraining excessive fuel in the gas pushed out of the tank.

As with fuel scrubbing, the spent ullage wash gas is expected to contain volatile organic composition from the fuel. Accordingly, this invention also provides for cleaning a significant, and preferably a major fraction of the fuel vapor from the spent ullage wash gas prior to discharge to the ambient atmosphere. Techniques for cleaning the spent ullage wash gas are similar to those for fuel scrubbing waste gas described above.

From this disclosure it should be evident that a substantial quantity of fresh, inert gas can be consumed in fuel scrubbing and ullage washing of aircraft fuel tanks at a facility of moderate to high air transportation activity. To satisfy these large volume needs, on-ground inert gas supply facilities are preferred. Furthermore, due to its plentiful availability, nitrogen is the preferred inert gas for fuel scrubbing and ullage washing

utilities. This invention provides for removing oxygen from ambient air to provide a nitrogen enriched gas which can then be used for scrubbing and washing.

In accordance with this invention, nitrogen enriched inert gas for fuel scrubbing and ullage washing can be produced *in situ* at ground based aircraft fuel dispensing sites such as tank farms and fuel storage depots. That is, the inert gas can be generated on-demand which obviates the need to stockpile enormous quantities of substantially oxygen-free cryogenically liquefied gas. Instead of being transported from a distant, off-airport site as cryogenic liquid in cargo tanks, the inert gas is produced at one or more on-site locations positioned near fuel storage depots for bulk fuel scrubbing and optionally near aircraft fuel tank loading sites near cargo loading and passenger boarding terminals for ullage washing.

Non-cryogenically liquefied nitrogen enriched inert gas is produced by removing at least some of the oxygen present in ambient atmospheric air. Representative methods of extracting oxygen from air to produce nitrogen enriched inert gas are pressure swing adsorption and membrane separation. In pressure swing adsorption, ambient air is compressed and passed through a bed of an adsorbent material which is selectively adsorbent for oxygen and other components of air. Illustrative adsorbent materials include molecular sieves and silica gel. Oxygen from the compressed air adsorbs onto the bed permitting nitrogen and other inert components to flow through and out of the bed. The nitrogen enriched product can be used immediately or stored for later use.

The adsorbent material laden with oxygen is then depressurized and swept with air to desorb oxygen and thereby regenerate the material to a condition suitable for adsorbing additional oxygen. Pressure swing adsorption processes thus usually operate in cyclical fashion. Typically multiple pressure swing adsorption beds are ganged together within a unit and controlled to allow regeneration of some beds while others draw oxygen from air. With appropriate controls and accessory equipment a supply of nitrogen enriched inert gas of substantially constant pressure and flow can be produced by multiple bed pressure swing adsorption units.

Membrane separation for production of nitrogen enriched inert gas for use according to this invention usually involves contacting air of an initial nitrogen concentration, for example ambient atmospheric concentration air of approximately 79 vol. % nitrogen and 21 vol. % oxygen, with a selectively gas permeable membrane having a preference for transmembrane transfer of oxygen relative to nitrogen. That is, oxygen permeates the membrane faster than nitrogen so that oxygen enriched air is produced on the permeate side of the membrane while nitrogen enriched inert gas is produced on the retentate side. Membrane separation advantageously produces nitrogen enriched inert gas steadily while inlet air is fed to the membrane. Oxygen enriched gas is drawn away from the permeate

side of the membrane and nitrogen enriched inert gas is collected from the retentate side of the membrane. Hence membrane separation units do not normally operate cyclically as do pressure swing adsorption units.

The material for the selectively gas permeable membrane suitable for generating nitrogen enriched inert gas from ambient air composition is preferably a polymer composition having an optimum combination of permeance and oxygen/nitrogen selectivity. Representative compositions of oxygen/nitrogen selectively gas permeable membranes include silicone rubbers, polysiloxane, polycarbonates, silicone-containing polycarbonates, brominated polycarbonates, polysulfones, polyether sulfones, sulfonated polysulfones, sulfonated polyether sulfones, polyimides, polyether imides, polyketones, polyether ketones, polyamides, polyamide/imides, polyolefins such as polyethylene, polypropylene, polybutylene, poly-4-methyl pentene, polyacetylenes, polytrimethylsilylpropyne, and fluorinated polymers such as tetrafluoroethylene and perfluorodioxoles.

The selectively gas permeable membranes can be in a variety of shapes and typically are flat films or hollow fibers containing a selectively gas permeable material. Preferably the gas permeable membrane is very thin to promote high gas flux. A non-uniform density profile or composite membrane structure is preferred. In a non-uniform density profile membrane the body of the membrane contains pores or voids such that the density of the structure varies with distance from one side of the membrane to the other in the transmembrane flux direction. The non-uniformity is preferably asymmetric in that the membrane has a dense skin on one side and incorporates voids increasing in concentration with distance from the one side. It is especially preferred that the dense skin is on the side of the membrane in contact with the feed composition and that the membrane is least dense on the permeate contact side. In a composite structure the selectively gas permeable membrane element can overlay on a structurally supportive substrate such as a porous membrane, screen or mesh.

The membrane can be configured in a device or module that incorporates multiple membrane layers or a multiplicity of hollow fiber membranes. Typical membrane forms include flat sheet, plate and frame and spiral wound.

Hollow fiber membranes are preferred because of the ability to combine a large number of ultra fine diameter hollow fibers in a single membrane module to provide a collectively immense gas transfer surface area within a relatively small overall module volume. Oxygen/nitrogen selectively gas permeable membranes of the hollow fiber type for use in the present invention are available from MEDAL division of Air Liquide, Newport, Delaware.

A more complete description of pressure swing adsorption and membrane separation processes and equipment suitable for producing nitrogen enriched inert gas for use according to the present invention is given in U.S. Patent No. 5,388,650 which is incorporated herein by reference in its entirety.

5 A further aspect of this invention is directed to providing a system adapted for deployment at and/or in close proximity to an airport and which is operative to reduce or eliminate the risk of explosion hazard within the fuel tank of all types of airplanes, and especially commercial airline craft. This aspect of the invention deals with the removal of a portion of the oxygen from the gas head space above the liquid fuel in the airliner
10 fuel tanks as well as the prior reduction of the dissolved oxygen content of the liquid fuel itself. These aspects of the invention can result in the exhaust to atmosphere of some inert gas bearing entrained volatile organic components ("VOC"). Accordingly, the novel system provides environmental control elements adapted to limit potential environmentally hazardous emissions during treatment of the fuel. Another feature of
15 this aspect of the invention is that certain redundancy is built in, *i.e.*, back up supply of inerting gas is provided. This feature advantageously enhances the reliability of the system.

Embodiments of this aspect of the present invention can best be understood with reference to Figs. 4 and 5. The system is intended to service the fuel tanks of aircraft 4
20 while on the ground, and preferably while the aircraft are positioned near the passenger boarding or cargo loading terminal buildings which are typically characterized by an elongated concourse 5. Other concourse arrangements may be used at different airports, largely depending upon the size and nature of the airport (e.g., passenger/cargo/combo and public or private air transportation). The arrangement
25 of the concourse shown in Fig. 4 is not limiting to the applicability of this invention.

A tank farm of one or more (three shown) aircraft fuel bulk storage tanks 6 is usually located some distance from the boarding/loading concourse. Appropriate valves (not shown) are provided to permit using any one of the bulk storage tanks 6 alone or in combination with other such tanks. The bulk storage tanks deliver fuel for loading into
30 the aircraft onboard fuel tanks from the tank farm through a supply transfer line 7 which extends along the concourse and has a number of delivery ports 9. The ports are located conveniently near the aircraft boarding/loading areas of the concourse. Each port is equipped with conventional block valve and hose and hose connection (not shown) which are used to connect the fuel supply transfer line to the onboard fuel tank of an
35 aircraft to be filled with fuel.

According to this invention, the fuel delivered to the aircraft is deoxygenated to a low dissolved oxygen concentration while in or near bulk storage tanks 6. Fresh aircraft fuel,

typically jet fuel type "A1" is supplied to the bulk storage tanks via inlet transfer line 8. This fuel usually contains dissolved oxygen absorbed from the air during normal course of manufacture and transfer to the tank farm. The dissolved oxygen content of the fresh fuel can be about 50 parts per million by weight ("ppm") or more. If liberated from the liquid fuel during depressurization as an aircraft ascends during flight, this amount of dissolved oxygen could raise the concentration of oxygen in the aircraft fuel tank head space. A goal of this invention is to remove enough dissolved oxygen from the fuel that liberation of any remaining dissolved oxygen during flight is unable to elevate the oxygen concentration in the fuel tank head space above an unsafe level. Thus it is desired to provide a dissolved oxygen content of the fuel such that the head space oxygen concentration is below a preselected limit. It is preferred to reduce the dissolved oxygen concentration of the fuel in bulk storage to less than about a 5 ppm and more preferably to less than about 3 ppm prior to loading the fuel on board aircraft.

Fuel deoxygenation is accomplished by a process that takes place utilizing equipment within the border section 2 of Fig. 4 that is shown in Fig. 4 and described in greater detail below. This process consumes a very low oxygen concentration inert gas stream 10, such as nitrogen. Preferably, the gas is high purity nitrogen having oxygen concentration of less than about 0.5 vol. %, and more preferably, at most about 0.1 vol. % oxygen. Such high purity nitrogen can be produced from ambient air utilizing an on-site, high purity nitrogen enriched air generator such as an APSA™ Advanced Product Supply Approach system (A in Fig. 4).

The APSA system produces nitrogen enriched air from ambient air basically as follows. Water, carbon dioxide and other airborne impurities, such as dust, particulate matter and aerosols of water and/or oil, are removed from the compressed air which is then cooled in a heat exchanger and fed into a column. Cryogenic distillation is carried out in the column which contains a column packing to promote separation of nitrogen from the air in accordance with conventional distillation principles. During the cryogenic distillation, nitrogen is separated from the nitrogen/oxygen mixture of the feed air. The column is normally oriented vertically allowing for liquid nitrogen to cascade downward while nitrogen/oxygen gas mixture flows upward. In simple terms, the oxygen condenses in contact with falling liquid nitrogen while nitrogen gas continues to rise through the column. Nitrogen product and waste gases are made to flow through the heat exchanger and cools the incoming fresh air to be separated. The nitrogen product flows through conventional flow control and measurement instruments, including oxygen analysis and leaves as a compressed gas stream. Multiple columns can be deployed within the APSA system to optimize flow and extent of separation (i.e., nitrogen purity). The specific arrangement, size and details of each element in the APSA system are

selected to meet the requirements of a particular nitrogen enriched air production operation.

The APSA system is initially charged by a supply of ultra high purity liquid nitrogen, preferably greater than 99.99 vol. % nitrogen obtained from a liquid nitrogen storage vessel 14. This ultra high purity nitrogen can be fed to the APSA system (via line not shown) to start the system from a shut down condition. The storage vessel also supplies liquid nitrogen 15 that is vaporized in heat exchanger 16 to form ultra high purity nitrogen gas 17 that can back up the APSA system when it is out of service, for example, for maintenance. The ultra high purity nitrogen product gas from the APSA serves as a source of deoxygenating nitrogen for the bulk storage tanks 6 by feeding via transfer line 10 from the APSA system or line 10 and 17 from the liquid storage tank.

As a result of deoxygenating the stored fuel, the bulk storage tanks 6 discharge an off gas stream 12 which contains mostly excess inert gas, the oxygen removed from the fuel and some fuel vapor. The off gas 12 is stripped of substantially all fuel vapor to recover the entrained fuel. This not only allows economical use of the fuel vapor but prevents contamination of ambient air by VOC of the fuel when any of the gas from the stripping operation is vented to atmosphere. The off gas stream is stripped in a condensation unit operation S such as a Solval™ VOC Removal and Recovery system. The condensation unit is cooled by liquid nitrogen refrigerant 20 supplied by the liquid nitrogen storage vessel 14.

The Solval system S strips fuel vapor from noncondensable gas as follows. The fuel vapor bearing off gas is blown through the shell side of a shell and tube heat exchanger while liquid nitrogen flows through the high heat transfer efficient finned tubes. The liquid nitrogen is vaporized to cool the off gas to below about -17.8°C (0°F), and preferably, below about -45.6°C (-50°F), thereby condensing and separating the fuel as liquid from the slightly oxygen contaminated nitrogen off gas. The Solval system internally can include a preliminary stage condenser refrigerated with a pumped loop of a relatively high cryogenic temperature fluid such as cool methanol. This preliminary stage condenser prevents higher freezing point compounds from accumulating on the nitrogen refrigerated heat exchangers. Multiple trains of condensers and/or heat exchangers can be deployed to assure that a fully defrosted path through the Solval system is available at all times. Recovered condensed fuel vapor is returned to the fuel storage tanks 6 as a liquid via line 13 by a conventional pump and valving subsystem (not shown). The ultra high purity nitrogen vapor 19 from the liquid nitrogen generated in system S is returned to the fuel storage tanks through control valve 11 via transfer line 10. Thus, the ultra pure nitrogen from system S supplements the high purity nitrogen produced by unit A. Preferably system S is located in close proximity to the tank farm.

The Solval system produces a "clean" nitrogen stream 21 of substantially fuel-free nitrogen containing at most about 0.5 vol. % oxygen. This stream 21 can be vented through valve 26 to the atmosphere. Optionally, the low oxygen content nitrogen stream can be compressed by compressor 22 and then transferred through line 24 to the
5 concourse for use in aircraft fuel tank head space inerting as will be subsequently explained. Factors which might affect the decision whether to salvage rather than vent this stream include the distance between the Solval system and the fuel tank head space inerting system, the availability of a an existing spare transfer line 24 or the need to provide a new line, and the size and cost of operating compressor 22. As an additional
10 option, compressed fuel-free, low oxygen content nitrogen from the discharge of compressor 22 can also be fed into line 19 using a transfer line and valve subsystem (not shown) so that the clean nitrogen returns to the storage tank deoxygenation system. As mentioned, the clean nitrogen return contains some oxygen. However, purity of nitrogen for successful operation of the storage tank fuel deoxygenation system can be maintained
15 by controlling the proportion of clean nitrogen to ultra purity nitrogen from unit A. The ratio of cleaned nitrogen to ultra high purity nitrogen as well as all important process variables of the entire aircraft fuel tank inerting system can be controlled with a conventional digital control system T. The bulk storage fuel deoxygenation system can understood with reference to Fig. 5. Like elements of the figures are referenced with the
20 same numbers. Fresh liquid aircraft fuel enters tank 6 through supply line 8. The liquid fuel settles within the tank to a level defining a liquid-vapor interface shown as dashed line 30. Deoxygenated liquid fuel 32 is pumped by pump 33 through transfer line 7 to the aircraft at the concourse. Deoxygenation is accomplished according to this invention by circulating a flow of liquid fuel 32 through circulation pump 35 via line 37 to eductor
25 E and back to tank 6 via line 39. Lines 8 and 39 can discharge into tank 6 either above or below the liquid surface 30.

Within eductor E the recirculating fuel from line 37 is forced through a venturi nozzle at high flow rate. Ultra high purity nitrogen from unit A is fed into eductor E via
30 line 10 so that this nitrogen intimately mixes with the circulating fuel in turbulent flow conditions. In this way oxygen dissolved in the fuel equilibrates with the nitrogen and thereby largely leaves the liquid fuel and enters a gaseous nitrogen phase. By positioning the eductor above the storage tank, it is possible to have the deoxygenated fuel drain back into tank 6. In an alternate arrangement, the eductor can be postioned alongside tank 6 in which case a pump can be used to return oxygen depleted fuel to the tank.

35 The rate of ultra high purity nitrogen flowing into eductor E is continuously adjusted by control valve 40. The valve is automatically manipulated by a closed loop control system represented by element 42. The control system includes a dissolved oxygen

concentration analyzer with a transducer element positioned to sample the deoxygenated fuel draining from eductor **E** in line **39**. The control system parameters are preferably defined and programmed by the automatic digital control system **T**. The control system is set to admit an effective flow of ultra high purity nitrogen gas as needed to reduce the dissolved oxygen concentration in the fuel below a predetermined set point. The flow of recirculating fuel through line **37** optionally can also be throttled by a valve and control loop (not shown) operated by the digital control system to help produce the desired degree of deoxygenation. In general, the ratio of nitrogen to circulating fuel is increased to decrease the concentration of oxygen in the deoxygenated fuel.

Nitrogen bearing the stripped oxygen from the fuel flows from the top of the eductor via line **41**. The dilution effect of the nitrogen from unit **A** is such that the oxygen concentration in the eductor overhead gas stream is very low, and preferably below about 0.5 vol. %. This low oxygen concentration stream is added to a make up flow **44** of ultra high purity nitrogen. The oxygen is thereby further diluted to still lower concentration before entering the head space of tank **6** via line **45**. The purpose of the make up flow is to maintain a slightly positive pressure, low oxygen content, inert gas atmosphere in contact with the liquid fuel in the tank so that oxygen from the ambient atmosphere cannot infiltrate and re-dissolve into the liquid fuel. Excess gas is vented from the tank via line **12** and directed to the system **S** (Fig. 4.). The pressure in the tank is kept a small amount above atmospheric pressure by a back pressure device e.g., valve or regulator **36** in line **12** (Fig. 5) and/or an adjustable flow rate controlling fan **18** (Fig. 4).

The amount of make up nitrogen is adjusted by control valve **46** which is throttled under direction of a closed loop automatic vapor control system **V**. This control loop utilizes a pressure sensor and an oxygen vapor concentration analyzer (collectively shown as element **47**). The control system monitors the tank head space pressure which can rise and fall due to rising or lowering liquid fuel inventory as well as changing rate of make up flow. The control system also checks that the oxygen concentration in the head space. The vapor control system using control link **48** thus causes valve **46** to admit more or less ultra high purity nitrogen as necessary to maintain tank head space pressure above a minimum set point and to keep the oxygen concentration of the vapor below a maximum, preferably at most about 2 vol. %. The vapor control system can optionally supervise the activity of the back pressure device in line **12** via control link **49**.

A preferred embodiment of the fuel scrubbing system is shown in Fig. 6. This diagram shows three bulk fuel storage tanks **6** that commonly feed scrubbed fuel to aircraft fuel tanks (not shown) via a common transfer line **63**. Raw fuel **62** potentially having high oxygen content enters the system in eductor **E**. There it is contacted in

turbulent flow with gaseous nitrogen 69 as previously explained to transfer oxygen from the fuel to the nitrogen. The mixture 66 of deoxygenated fuel and oxygen-entrained nitrogen drop to a conventional gas/liquid separator 68 where the gaseous components depart usually upward to gas manifold 64 while scrubbed liquid fuel continues downward to feed the bulk storage tanks. The oxygen-containing nitrogen that also entrains fuel vapor can transport to fuel recovery unit S. Also as previously explained, this unit contacts the fuel/nitrogen/oxygen gas stream with cold liquid nitrogen 61. This discharges an oxygenated nitrogen gas stream 63 for disposal and returns a deoxygenated, condensed fuel product 67. The condensed fuel 67 joins the eductor scrubbed fuel and drains into the bulk storage tanks 6. Each tank is kept blanketed with slightly positive pressure, nitrogen gas 69 to assure that oxygen in ambient air does not enter the tanks as the tanks feed fuel. The atmosphere in the tanks is controlled by control systems V. As above, these sense pressure and oxygen concentration in the tank and throttle valves in the nitrogen supply lines 69 and vent lines 65 to maintain desired set points. Arrows in vent lines 65 are shown to point in opposite directions. This is meant to convey that gas in these lines can flow in either direction depending on the dynamics obtaining at a given point in time. For example, if a particular tank 6 is feeding scrubbed fuel forward, its liquid level will drop and it can accept some fuel/nitrogen gas from separator 68 to replace the volume of liquid fuel discharged. Of course, the vapor control system V will prevent too much oxygen of the fuel/nitrogen gas stream in header 64 from entering the tank 6. Additional make up nitrogen is provided through the appropriate nitrogen line 69. By way of another example, when fuel fills a particular tank 6, the liquid level will rise and displace gas from the tank head space. This gas containing fuel vapor and nitrogen can flow into the fuel nitrogen gas stream header 64. From there it will be treated in recovery unit S. The fuel vapor will ultimately be returned to tanks 6. This embodiment permits a single eductor to scrub fuel for a farm of tanks. Advantageously, the tanks can be in different states simultaneously, *i.e.*, feeding (liquid level descending), filling (liquid level rising) and storing (liquid level stationary). Therefore, this system provides a constant ready supply of scrubbed fuel.

With further reference to Fig. 4., use of the novel system to render aircraft fuel tanks inert will be explained next. Deoxygenated fuel from bulk storage tanks 6 is delivered to the aircraft boarding/loading concourse 5 via transfer line 7 as mentioned. The deoxygenated fuel is distributed at the concourse to individual aircraft through ports 9 proximate to each gate where aircraft can be boarded and/or loaded. The fuel can be charged into the on-board fuel tanks using conventional valves and flexible hoses in the customary manner.

The head space of the on-board aircraft fuel tanks should be "inerted" preferably prior to and during charging of the deoxygenated fuel. As above, by "inerting" is meant that the gas in the vapor space above the fuel in the tank, *i.e.*, the "ullage", should be replaced by low oxygen concentration inert gas. The gas can be argon, carbon dioxide, nitrogen or another such gas. Nitrogen is preferred. The oxygen concentration of the head space should be reduced to less than about 12 vol. %, preferably at most about 9 vol. % and more preferably at most about 5 vol. %. The reduction can be accomplished by purging the head space with the low oxygen-content inert gas. A preferred source of inert gas according to the present invention is highly nitrogen enriched air having a nitrogen concentration of at least about 95 vol. %, more preferably at least about 97 vol. % and most preferably at least about 98 vol. %.

Highly nitrogen enriched air for head space inerting can be produced from ambient air having about 79 vol. % nitrogen and about 21 vol. % oxygen with a selectively permeable gas separation membrane system. These systems are well known in the art. Initially the ambient air is filtered to remove dust and cleaned of water in aerosol form. Very basically, the nitrogen enriching membrane separation system functions by contacting ambient air with one side of the membrane. Usually, oxygen permeates the membrane at higher rate than nitrogen producing a composition of high oxygen concentration on the opposite, so-called "permeate" side of the membrane. This leaves a nitrogen-rich gas composition on the first, occasionally called "retentate" side of the membrane. A typical selectively gas permeable membrane system for producing highly nitrogen enriched air from ambient air is commercially available under the tradename "Floxa".

As seen in Fig. 4, ambient air 3 is taken in to a highly nitrogen enriched air supply facility F. This supply facility produces an oxygen enriched air stream (not shown) which can be safely vented to the ambient atmosphere. The highly nitrogen enriched air 23 is conveyed by a distribution header line 25 along the aircraft boarding/loading concourse 5 where it can be distributed in proximity to various aircraft through a plurality of nozzles 27. Each distribution nozzle can be connected to the on-board aircraft fuel tanks by valves and flexible hoses (not shown). For example, the highly nitrogen enriched air can be connected to a head space port for this purpose or the fuel filling hose nozzle can be adapted to accommodate a connection to the supply of highly nitrogen enriched air. The highly nitrogen enriched air can be charged into the head space of the tank or injected below the liquid fuel level and thereby made to bubble through the on-board fuel. In either case, a sufficient amount of highly nitrogen enriched air is blown into the on-board fuel tank to displace the existing head space atmosphere with low oxygen content inert gas. Because the highly nitrogen enriched air supply unit

F is safe and clean to operate, it can be located in close proximity to the concourse, although location of the unit is not critical to operation of this invention.

Although the present invention has been described largely in terms of an airport having a single concourse having a single nitrogen enriched air source system F, and a single tank farm having a single VOC removal and recovery system S, it is contemplated that multiple concourses, tank farms, and systems S, F, A and T may be present. The number of each system will depend upon the size and type of use of a particular airport. Optionally, the system F at each concourse can be backed up with its own liquid nitrogen storage tank 55 and vaporizer 56 (Fig. 4) to produce nitrogen gas to supply the aircraft fuel tank inerting system through line 25 even when the nitrogen enriched air supply system F is out of service, (e.g., for maintenance). As an additional option, all of the nitrogen enriched air supply systems of each concourse can be manifolded together to form a nitrogen gas supply grid thereby allowing gas to be consumed at any point within the grid system without being dependent on any particular nitrogen enriched air supply system F. This additional option provides greater redundancy and further improved reliability.

It is thus apparent that the gas displaced from the head space of the on-board aircraft fuel tanks will likely entrain fuel vapor. If not otherwise contained, the displaced gas will emit undesirable VOC to the ambient atmosphere. Accordingly, the present invention optionally provides for the collection of VOC containing gas displaced from the on-board fuel tanks during the head space inerting step. To this end each aircraft boarding/loading position along the concourse additionally includes a nozzle adapted to receive the gas displaced from the on-board tank during fuel loading. The nozzle can be connected to the tank at a separate tank vent port, to a dedicated adapter fitted to the inerting gas supply line, or to a fitting on the fuel filling nozzle. The alternative of connecting the VOC collection line to the inert gas supply fitting provides the advantage that only a single new connection needs to be made to the fuel tank to feed the inert gas and to remove the displaced fuel vapors. The last alternative advantageously obviates the need to make any modifications to existing aircraft fuel tanks to accommodate inerting and VOC collection. The choice of method of connecting the inerting supply and the VOC collection lines will largely depend upon the nature of the aircraft and the configuration of its on board fuel tanks.

The various displaced fuel vapor receiving nozzles at each aircraft servicing station on the concourse are joined in fluid communication to a common collection header 29. The collection header containing fuel vapor is run back to the system S in which the fuel component is removed from noncondensable gas for recovery and reuse and the low VOC gas can be safely vented to atmosphere or utilized to deoxygenate or blanket the bulk

storage tanks. An optional compressor (not shown) can be provided to blow the collected VOC containing inerting gas back to unit S.

Because the fuel stripping unit can be located at a great distance from the concourse, returning the VOC-bearing spent inerting gas can be impractical. Accordingly, an optional additional fuel stripping system unit S2 can be installed closer by, (but at a safe distance from) the concourse. This additional fuel stripping system unit will operate similarly to the main system S and will have the same internal functional elements, although they normally will be of smaller scale. The VOC-bearing spent inerting gas from collection header can be drawn into unit S2 via line 50. The cleaned nitrogen enriched air can be vented to atmosphere and the condensed liquid solvent can be collected through line 53 to a small tank 54. Accumulations of condensed fuel can be transferred into drums or transported by other conventional methods to the main fuel tanks 6 for reuse. This S2 system unit can be powered by liquid nitrogen stored in the optional liquid nitrogen storage tank 55, described above.

The highly nitrogen enriched air supply system might be shut down temporarily for maintenance or other reason. Usually, sufficient overcapacity or redundancy can be built into the membrane system that there will be an adequate supply of highly nitrogen enriched air at all times necessary for fuel tank inerting. As a contingency, vaporized liquid nitrogen from the discharge of heat exchanger 16 can be supplied to distribution header 25 via transfer line 28.

As mentioned, the process of airliner tank inerting at the airport concourses, fuel deoxygenation at the fuel tank farm and the clean-up of the vent gas at the tank farm by the fuel recovery system S can all be monitored by a computer based control system T such as the proprietary Teleflo™ remote telemonitoring system. Such an industrial based computer system allows users to view real time variables, stored data and alarms, and to receive alarms when a part of the overall process experiences trouble. Communication is achieved over the standard telephone lines or satellite link-up. An "APSA" ultra high purity nitrogen generation system, A, a "Solval" fuel stripping facility, S, a "TeleFLO", supervisory digital control system, T, a Vestal™ vapor concentration management system "V", an eductor E, and a "Floxxal" highly enriched nitrogen air supply system, F, are each available from Air Liquide America, Houston, Texas.

Although only preferred embodiments have been specifically described above, it will be appreciated that it is possible to make modifications and variations of the preferred embodiment without departing from the spirit and intended scope of the invention.

What is claimed is:

1. An inerting system for inerting a flammable composition comprising a flammable vapor and oxygen in a vented, controlled atmosphere container, comprising:

(i) a container;

(ii) an outlet in said container for said flammable composition;

(iii) a compressor, in fluid communication with said outlet, which compresses the flammable composition from the container;

(iv) a separator, in fluid communication with said compressor for removing oxygen from said flammable composition to produce an oxygen-depleted composition; and

(v) an inlet in said container, which is in fluid communication with said separator, through which said oxygen-depleted composition is fed into said container.

2. The system of claim 1, further comprising a supply of makeup gas to replace any lost volume of gas expelled from said container during operation of the inerting system.

3. The system of claim 2, wherein said makeup gas is oxygen-depleted air.

4. The system of claim 2, further comprising a second separator for removing oxygen from air to obtain said make-up gas of oxygen-depleted air.

5. The system of claim 4, further comprising a source of compressed air for feeding air to said second separator.

6. The system of claim 4, wherein said second separator is a membrane separator.

7. The system of claim 1, in which said vented container is a fuel tank.

8. The system of claim 7, in which said flammable composition is fuel tank ullage.

9. The system of claim 1, in which said separator is a membrane separator.

10. The system of claim 1, in which said separator is a pressure swing absorption separator.

11. A method of inerting a flammable composition, comprising a flammable vapor and oxygen, in a vented controlled atmosphere container comprising the steps of:

- (i) removing said flammable composition from said container;
- (ii) compressing said gas;
- (iii) removing an amount of oxygen from said flammable composition to produce an oxygen-depleted composition; and
- 5 (iv) feeding said oxygen-depleted composition into said container.

12. The method of claim 11, further comprising the step of feeding an amount of oxygen-depleted makeup gas to the container.

- 10 13. The method of claim 12, in which the amount of oxygen-depleted makeup gas fed into the container substantially corresponds to the amount, by volume, of oxygen depleted from said flammable composition.

- 15 14. The method of claim 12, in which said step of feeding an amount of oxygen-depleted makeup gas to the container comprises the steps of removing an amount of oxygen from air to obtain an oxygen-depleted air and feeding the oxygen depleted air to said container.

- 20 15. The method of claim 14, comprising removing oxygen from compressed air.

16. The method of claim 14, comprising removing oxygen from air by pressure swing absorption.

- 25 17. The method of claim 14, comprising removing oxygen from air by a selectively gas permeable membrane.

18. The method of claim 11, in which said container is a fuel tank.

- 30 19. The method of claim 18, in which said flammable composition is fuel tank ullage.

20. The method of claim 11, comprising removing oxygen from said flammable composition by membrane separation.

- 35 21. The method of claim 11, comprising removing oxygen from said flammable composition by pressure swing absorption.

22. A method of reducing the potential for hazard from combustion of an aircraft fuel tank having an ullage comprising the steps of

(a) providing a feed stream of air at a ground based aircraft fuel dispensing site,

(b) removing at least a major fraction of the oxygen from the feed stream at the aircraft fuel dispensing site thereby obtaining a nitrogen enriched gas and a byproduct of oxygen enriched gas, and

(c) utilizing the nitrogen enriched gas to reduce the oxygen concentration within the aircraft fuel tank of an on-ground aircraft comprising scrubbing a fuel in the aircraft fuel tank having an initial dissolved oxygen concentration with an amount of the nitrogen enriched gas effective to reduce the concentration of oxygen dissolved in the fuel to a value below the initial dissolved oxygen concentration operative to render the fuel incapable of forming an explosively combustible concentration of oxygen in the ullage during fuel tank operation in flight.

23. The method of claim 22 in which scrubbing the fuel takes place prior to placing the fuel into the aircraft fuel tank.

24. The method of claim 22 or 23 in which the concentration of dissolved oxygen is reduced such that the oxygen exerts a partial pressure of at most about 20.7 kPa absolute (3 psia).

25. The method of any of claims 22-24 in which the scrubbing step comprises sparging the fuel with the nitrogen enriched gas.

26. A method of reducing the potential for hazard from combustion of an aircraft fuel tank having an ullage of an oxygen-containing gas mixture, comprising the steps of

(a) providing a feed stream of air at a ground based aircraft fuel dispensing site,

(b) removing at least a major fraction of the oxygen from the feed stream at the aircraft fuel dispensing site thereby obtaining a nitrogen enriched gas and a byproduct of oxygen enriched gas, and

(c) utilizing the nitrogen enriched gas to reduce the oxygen concentration within the aircraft fuel tank of an on-ground aircraft comprising admitting the nitrogen enriched gas into the ullage, blending the nitrogen enriched gas with the oxygen-containing gas mixture, exhausting the blended oxygen-containing gas mixture, and

continuing the admitting, blending and exhausting steps for a time effective to reduce the concentration of oxygen in the ullage to less than about 12 vol. %.

27. The method of any of claims 22-26 which further comprises the steps of
5 discharging from the fuel a waste stream comprising oxygen and volatile organic components, withdrawing at least a major fraction of volatile organic components from the waste stream, and then emitting the waste stream reduced in volatile organic components to ambient atmosphere.

10 28. The method of any of claims 22-27 in which the withdrawing step comprises a unit operation selected from the group consisting of controlled combustion, adsorption, absorption, membrane separation and condensation to separate a portion of the volatile organic components from the waste stream.

15 29. The method of any of claims 22-28 in which the removing step comprises contacting the feed stream with one side of a membrane which is selectively gas permeable oxygen relative to nitrogen.

20 30. The method of claim 29 in which the membrane is in the form of a non-uniform density profile hollow fiber.

31. The method of claim 30 in which the hollow fiber has a asymmetric density profile.

25 32. The method of claim 31 in which the membrane comprises a plurality of hollow fibers each having a lumen, the fibers being combined within an elongated module defining a shell side volume outside the fibers and within the module and the fibers further defining a tube side volume comprising the aggregate of the volumes of the lumina connected in parallel flow through configuration such that the removing step
30 comprises introducing the feed stream into the tube side volume or the shell side volume and removing a permeate flow from the module opposite from the feed stream.

33. The method of any of claims 22-28 claim 1 in which the removing step comprises pressure swing adsorption.

35 34. The method of any of claims 22-33 in which the nitrogen enriched gas comprises at least about 88 vol. % nitrogen.

35. A system for reducing accidental explosion hazard of aircraft fuel tanks comprising

(a) fuel scrubbing means for lowering the dissolved oxygen content of fuel in an aircraft fuel tank to a concentration that oxygen liberated from the fuel during flight produces an oxygen concentration of vapor in the fuel tank head space not exceeding a preselected limit,

(b) head space inerting means for purging the head space of the aircraft fuel tank with a substantially oxygen-free gas to provide an oxygen concentration of vapor in the head space to less than the preselected limit, and

(c) volatile organic compound removing means for separating substantially all volatile organic compound components present in vapor produced by the fuel scrubbing means and the head space inerting means prior to emitting such vapor to ambient atmosphere,

in which all of the fuel scrubbing means, head space inerting means and volatile organic compound removing means are positioned on ground at an airport.

36. The system of claim 35 in which the fuel scrubbing means and the head space inerting means are adapted to reduce the oxygen concentration of the vapor to at most about 12 vol. %.

37. The system of claim 35 in which the fuel scrubbing means is adapted to lower the dissolved oxygen concentration to at most about 5 parts per million by weight.

38. A system for reducing a hazard of accidental explosion of aircraft fuel tanks comprising at least one of

(A) a first supply of ultra high purity nitrogen gas comprising a means for removing water, carbon dioxide and airborne impurities from air thereby producing filtered air, a heat exchanger adapted to cool the filtered air and cryogenic distillation means for separating oxygen from the filtered air,

(B) a second supply of ultra high purity nitrogen comprising a tank containing pressurized, liquid nitrogen and a vaporizer means for vaporizing a stream of liquid nitrogen,

(C) an aircraft fuel bulk storage tank fuel scrubbing subsystem comprising a gas-liquid mixing means adapted to intimately mix liquid aircraft fuel in turbulent flow with nitrogen gas from at least one of the first supply and the second supply of

ultra high purity nitrogen, and a fuel circulation pump adapted to pump the aircraft fuel in a loop between the bulk storage tank and the gas-liquid mixing means,

5 (D) a volatile organic compound removing means comprising a condensing heat exchanger being operative to condense volatile organic compounds from a mixture of nitrogen gas and such volatile organic compound components, and a vent adapted to emit to ambient atmosphere nitrogen gas substantially free of the volatile organic compound components,

10 (E) an aircraft fuel tank head spacing inerting subsystem comprising a membrane separation unit adapted to produce highly nitrogen enriched air from ambient air and a highly nitrogen enriched air distribution header operative to deliver the highly nitrogen enriched air to each aircraft loading/boarding position of a concourse of the airport, and

15 (F) an aircraft fuel tank head space venting system comprising a vapor transfer line from the concourse of the airport to the volatile organic compound removing means, and means for removably connecting the vapor transfer line to the aircraft fuel tank head space of aircraft at each aircraft loading/boarding position of a concourse of the airport.

20 39. The system of claim 38 which comprises more than one element (A)-(F)

40. The system of claim 38 which comprises substantially all of the elements (A)-(F).

25 41. The system of claim 38 in which the volatile organic compound removing means is positioned proximate to the bulk storage tank and the system further comprises a second volatile organic compound removing means comprising a condensing heat exchanger operative to condense volatile organic compounds from a mixture of nitrogen gas and such volatile organic compound components, and a vent adapted to emit to ambient atmosphere nitrogen gas substantially free of the volatile organic compound components, the second volatile organic compound removing means being positioned proximate to the concourse and being adapted to receive nitrogen gas bearing volatile organic compound components discharged from the aircraft fuel tank head space.

35 42. The system of claim 38 which further comprises a third supply of ultra high purity nitrogen comprising a tank containing pressurized, liquid nitrogen and a vaporizer means for vaporizing a stream of liquid nitrogen, the third supply of ultra high purity nitrogen being adapted to provide nitrogen gas to the highly nitrogen enriched air

distribution header as an installed redundant source to the membrane separation unit, and in which the third supply of ultra high purity nitrogen is positioned proximate to the concourse.

5 43. The system of claim 39 which comprises a plurality of at least one of those of elements (A)-(F) and in which the plural elements are manifolded together to form a nitrogen gas supply grid, thereby allowing nitrogen gas to be consumed anywhere within the grid without depending upon operability of any particular one of the plural elements.

10 44. A system for reducing a hazard of accidental explosion of aircraft fuel tanks comprising

 (A) a plurality of bulk liquid aircraft fuel storage tanks adapted to discharge scrubbed aircraft fuel through a common discharge transfer line, each tank comprising a headspace vent, a high purity nitrogen supply, and a vapor control system adapted to
15 control feed of the high purity nitrogen gas and exhaust through the headspace vent of gas in the tank, thereby maintaining the pressure and concentration of gas in the tank at a desired set point,

 (B) an eductor adapted to receive and contact raw aircraft fuel containing dissolved oxygen with nitrogen gas, thereby transferring oxygen from solution in the
20 fuel to the nitrogen gas and producing scrubbed fuel,

 (C) a separator operative to segregate the scrubbed fuel from the nitrogen gas containing oxygen of (B),

 (D) a fuel recover unit adapted to condense aircraft fuel vapor entrained in the nitrogen gas containing oxygen of (B), and

25 (E) a gas stream transfer line in vapor communication with the separator, the fuel recovery unit and the vent of each tank.

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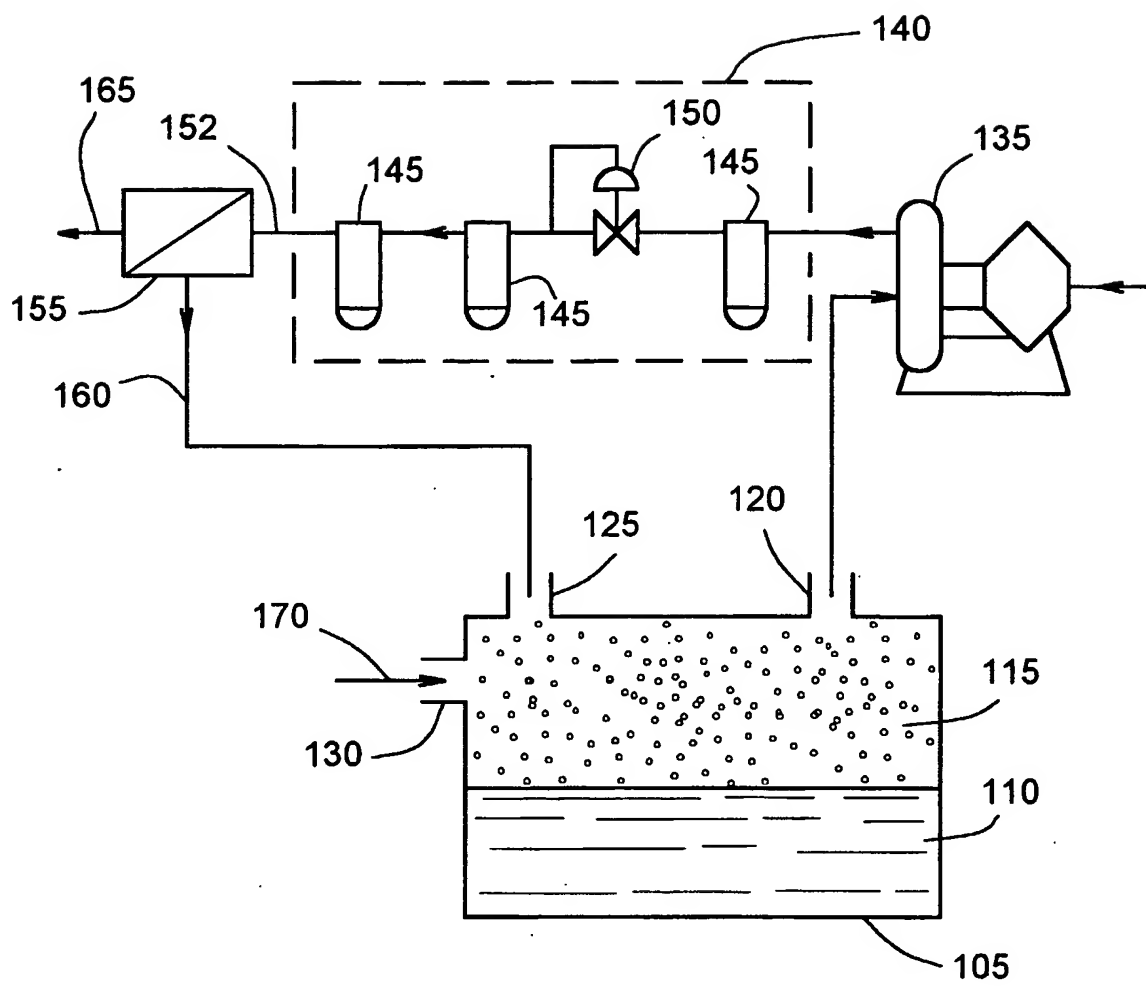


Fig. 1

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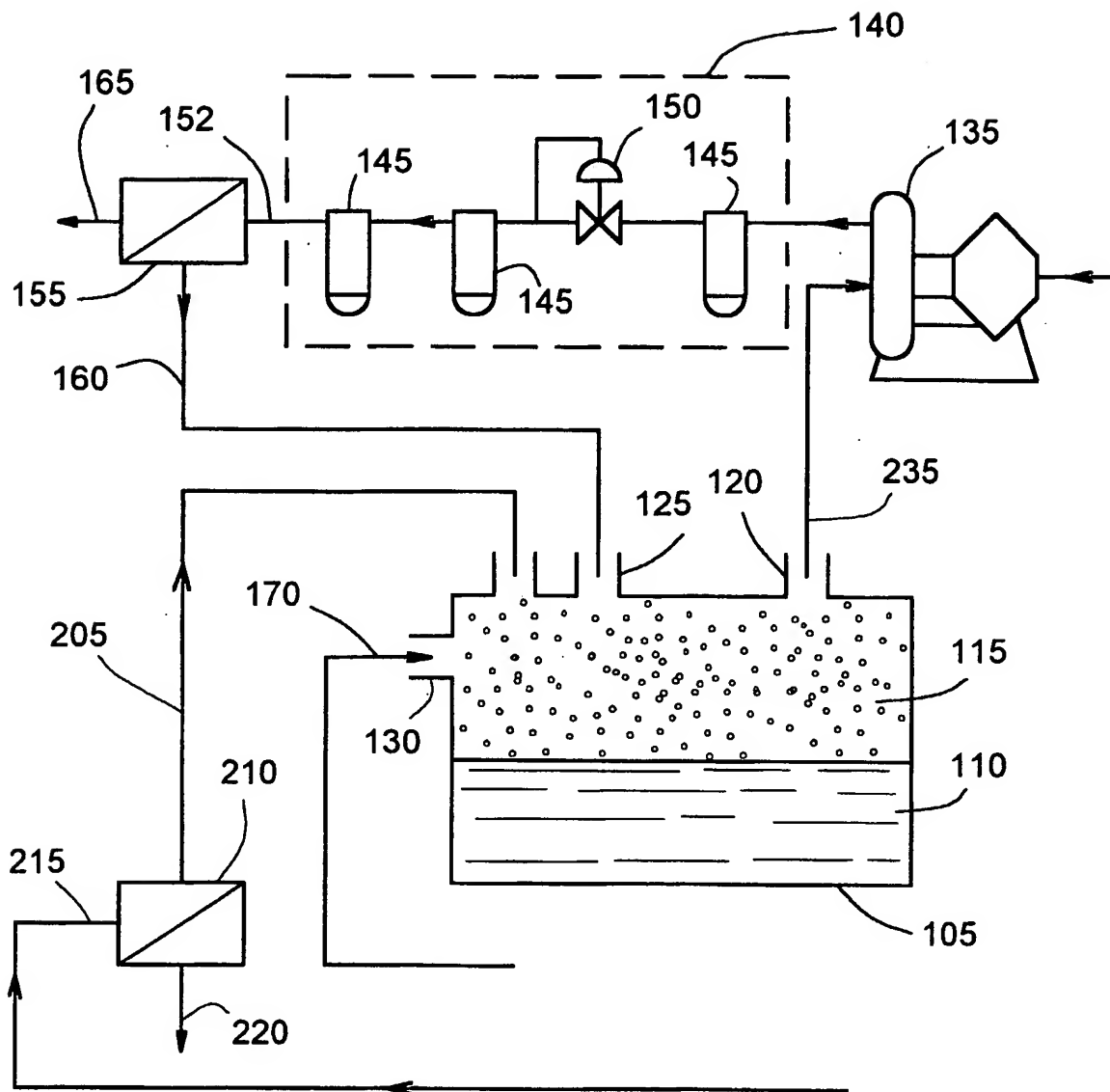


Fig. 2

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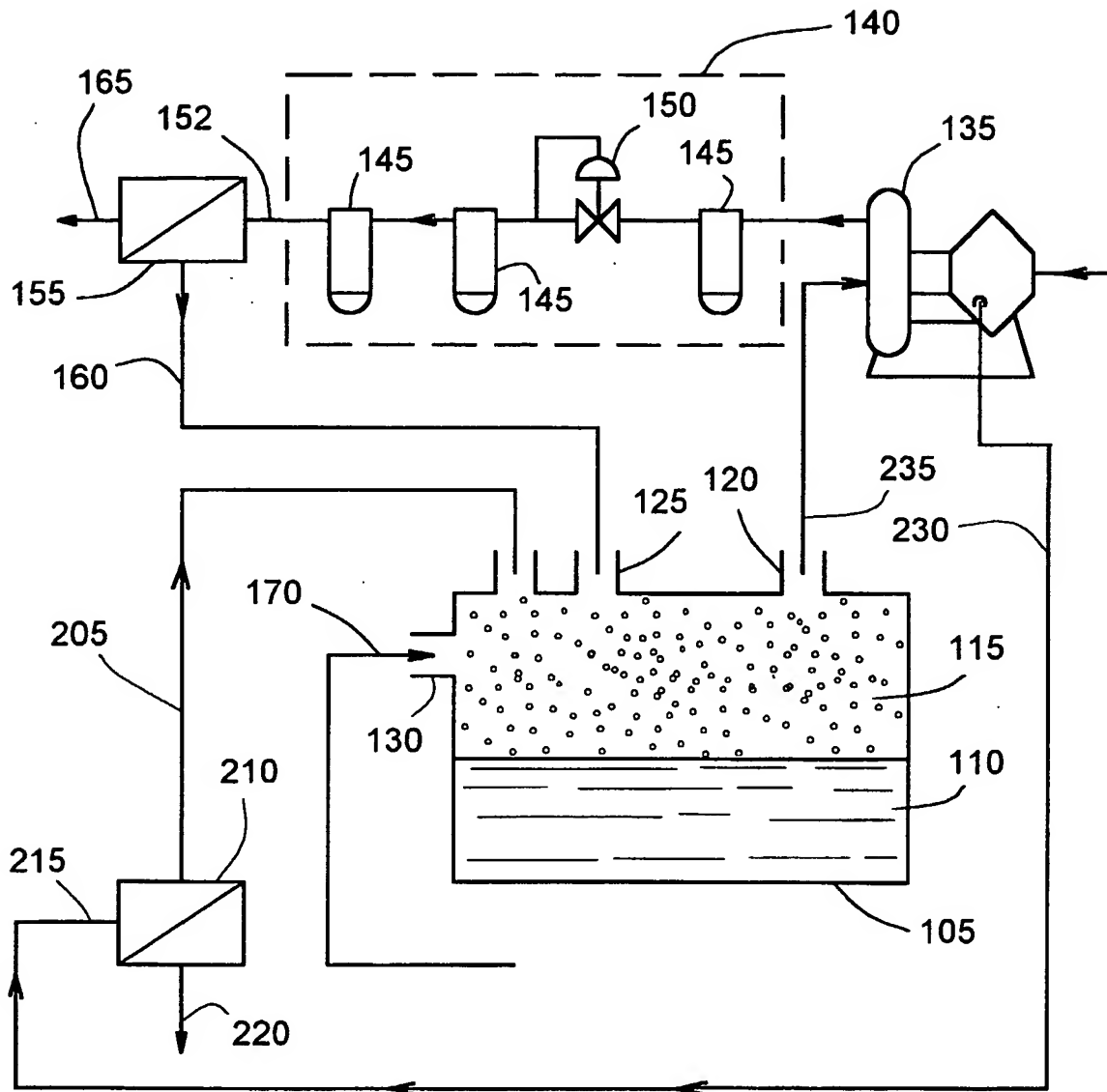


Fig. 3

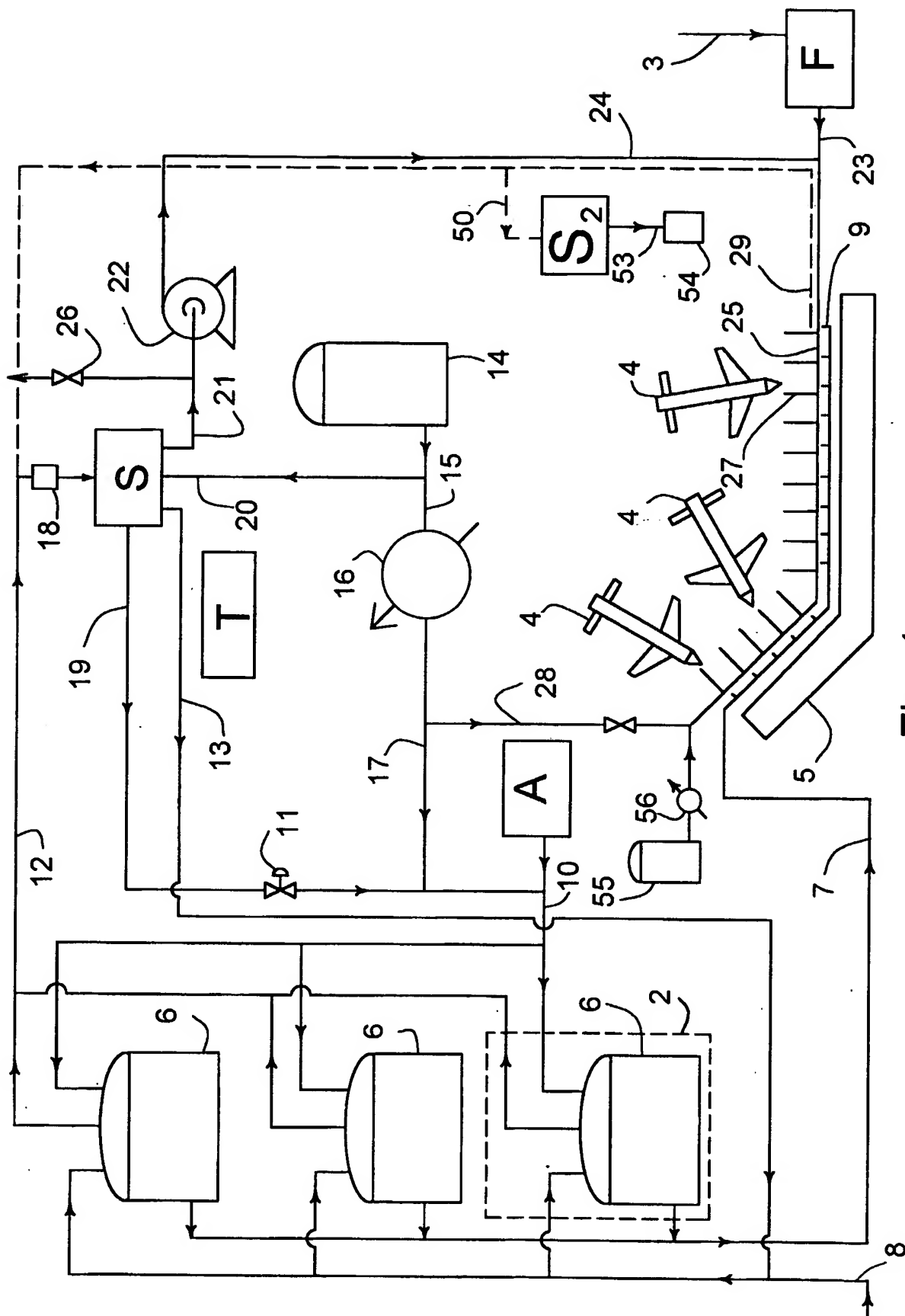


Fig. 4

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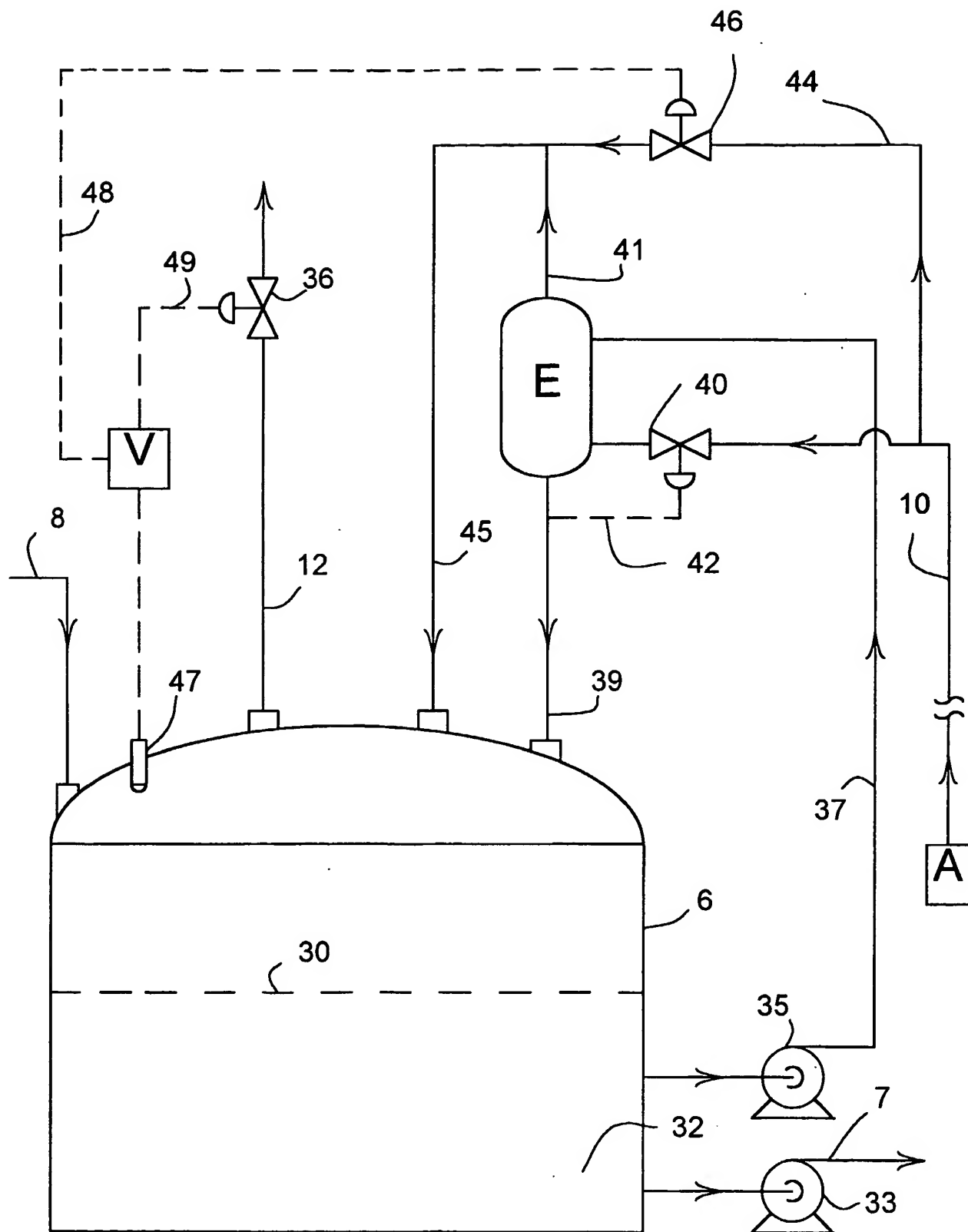


Fig. 5

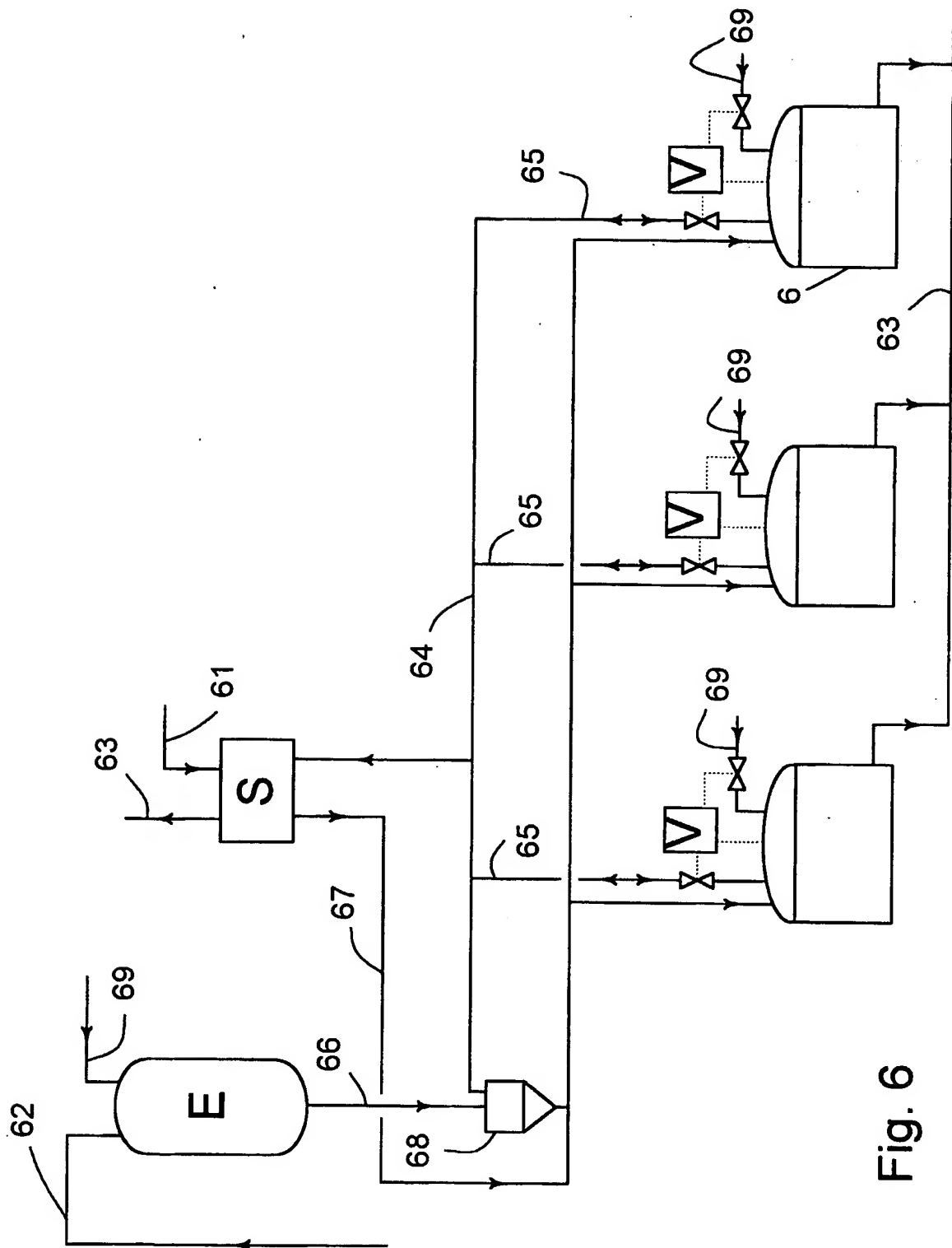


Fig. 6

A. CLASSIFICATION OF SUBJECT MATTER
 IPC 7 B64F1/28 B64D37/32 B65D90/44 A62C3/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 B64F B64D B65D A62C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 176 002 A (O'BRIEN JOHN V ET AL) 5 January 1993 (1993-01-05)	38
Y	abstract	35-37
A	column 2, line 26 - line 39 column 3, line 27 - line 48	1-3, 7, 8, 11-13, 18, 19, 38, 44
Y	US 3 948 626 A (BRAGG KENNETH R) 6 April 1976 (1976-04-06)	35-37
A	abstract	22-26, 34, 38, 44
	figure 2 column 3, line 32 - column 4, line 13	
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☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

29 January 2002

Date of mailing of the international search report

05/02/2002

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>US 3 691 730 A (HICKEY WILLIAM G. ET AL) 19 September 1972 (1972-09-19)</p> <p>abstract figure 1 column 1, line 57 - column 2, line 52 column 3, line 32 - line 38</p>	<p>22-26, 34, 35, 38, 39, 44</p>
A	<p>WO 99 34106 A (FUEL DYNAMICS ; KOETHE TERENCE LEE (US)) 8 July 1999 (1999-07-08) cited in the application page 4, line 1 - line 11 page 6, line 1 - page 8, line 29</p>	<p>22, 23, 26</p>
A	<p>WO 00 00389 A (AIR LIQUIDE ; BEERS KARL S (US)) 6 January 2000 (2000-01-06)</p> <p>the whole document</p>	<p>1-6, 11-15, 17, 22, 26, 34, 35, 38</p>
A	<p>US 5 388 650 A (MICHAEL KEITH) 14 February 1995 (1995-02-14) cited in the application</p> <p>abstract column 2, line 15 - line 24</p>	<p>1-6, 11-17, 22, 26, 33-35, 38</p>

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